

**SHIP PRODUCTION COMMITTEE
FACILITIES AND ENVIRONMENTAL EFFECTS
SURFACE PREPARATION AND COATINGS
DESIGN/PRODUCTION INTEGRATION
HUMAN RESOURCE INNOVATION
MARINE INDUSTRY STANDARDS
WELDING
INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING**

**September 1985
NSRP 0226**

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

**1985 Ship Production Symposium
Volume II
Paper No. 23:
CAD/CAM Directions for the U.S.
Navy**

**U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER**

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE SEP 1985		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE The National Shipbuilding Research Program 1985 Ship Production Symposium Volume II Paper No. 23: CAD/CAM Directions for the U.S. Navy				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Surface Warfare Center CD Code 2230-Design Integration Tools Building 192 Room 128 9500 MacArthur Bldg Bethesda, MD 20817-5700				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 22	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

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CAD/CAM DIRECTIONS FOR NAVY

By

CAPT. John F. Leahy

J. Christopher Ryan

Naval Sea Systems Command

CAD/CAM DIRECTIONS FOR NAVY

by: John F. Leahy III and J. Christopher Ryan

Brief ~~Historical~~ Review of navy CAD/CAM Projects

In the past two decades, the U.S. Navy has undertaken significant projects in the computer aided design, manufacturing, and service life support areas. A few of the those most related to the shipbuilding programs are listed in Table 1 along with the phase in the ship's life cycle they were primarily supporting.

TABLE 1
MAJOR NAVY CAD/CAM PROGRAMS

Title	Date	Emphasis		
		Design	Build	Maintain
CASDAC	1967	X	X	
ISDS	1969	X		
CAEDOS	1981		X	X
CSD	1982	X		
MAN/TECH	1982		X	
NICADMM	1986	X	X	X

o CASDAC (Computer Aided Ship Design and Construction) was the granddaddy of them all, dating back to the late 60s when the Navy was designing and building its own ships.. The project's goal was to develop software for doing early stage design, through contract design, and detail design at the naval shipyards. They labored under the dual burdens of expensive hardware and relatively unfriendly software development environment, with clumsy. operating systems, occasional need for assembly language programming, and early compiler limitations. Never-the-less, many programs that are still with us. today began during that era, including: SHCP (Ship Hull Characteristic Program) ; SSDP (Ship Structural Design Program); HULDEF (Hull form Definition); and SDWE (Ship Design Weight Estimating). The state of CASDAC's progress by the early and mid 70s is well described in references [1] and [2]. The monumental CASDOS (Computer Aided Structural Detailing Of Ships) was developed under CASDAC's sponsorship and actually used to build 6 LCUs for the Army and for Saudi Arabia. Over half of CASDAC's efforts were oriented toward shipyard production software, including electrical wiring and fluid piping systems programs. In 1981, long after the end of new ship construction at the Navy yards, CASDAC was subdivided into two distinct programs, the CSD (Computer Supported Design) project, carrying on the ship design software development, and portions of the MANTECH (manufacturing and technology) program for advancing industry's efforts to improve shipbuilding productivity through automation and technology.

o ISDS (Integrated Ship Design System) was also part of the

overall CASDAC project but warrants special note because of its similarity to current efforts in the CSD project. The ISDS system was supposed to be a cohesive set of computer programs for the design of Navy ships that was integrated through a common data base [3]. At that time, commercial DBMSs (Data Base Management System) were in their infancy and not oriented toward engineering (In fact, they still aren't with few exceptions). The ISDS Project thus also needed to develop its own DBMS, nicknamed COMRADE, along with the ship design software and the graphics capabilities. At that juncture, the Navy was at the forefront of ADP technology and presented numerous papers at the 1973 National Computer Conference [4,5,6]. Unfortunately, this landmark system was ahead of its time in its demands on computer resources and performance. It also suffered from being developed in a laboratory environment removed from the front line ship design activities and the associated "NIH" (not invented here) attitude from its supposed users. Its demise came after it had already tackled some of the most difficult technical problems of data base management and system architecture.

o CREDOS (Computer Aided Engineering and Documentation System) resulted from the need for a manufacturing-oriented system for Navy labs. The commercial CAD/CAM market was tapped in an attempt to provide up to date "turnkey" CAM capability to support general mechanical modelling/numerical control tape generation and some specialized production needs, such as for printed circuit boards. NW China Lake initiated the largest single purchase CAD/CAM equipment in history, ultimately valued at almost \$100M, for the benefit of all Navy labs and, subsequently, Navy shipyards. Computervision (CV) won the bid, delivering approximately 200 interactive graphics workstations over the period of 1982 to 1985. NAVSEA headquarters has used some of the CV workstations on the DDG51 and SSN21 designs to explore their utility in the early phases of ship design engineering. While CV provides powerful 3-D geometry modelling capability, its ability to support the analysis portion of naval ship engineering is minimal. Its greatest promise to engineering is as a part of an integrated system of modelling and analysis that the Navy must develop. The CREDOS contract capacity has been exhausted and will be replaced by a new CAD/CAM acquisition effort.

CSD (Computer Supported Design) is the continuation of CASDAC's early stage ship design software development effort. Formed in 1981, it has focused more intently on two facets: developing a working integrated system of ship design programs that are linked via a common data base; and the transfer of computer sensible data to the private shipbuilders at the end of the Contract Design phase. In the current terminology, CSD has become oriented toward the development of the ship "product model" and "digital data transfer". This is discussed in greater detail in the rest of the paper. Figure 1 shows the general time relationship of CSD, MAN/TECH and NICADMM programs.

o NICADMM (Navy Integrated Computer Aided Design Manufacturing and Maintenance system) is intended to be the common data base and interface system for the engineering related data to support the entire life cycle of a ship. This program is currently in the initial stages of formation. A "cradle to grave" system

NICADMM would use the "product model" developed by CSD to initialize the data base and continue its expansion during construction and the ship's service life for long term support of ship alterations and modernizations. This program is noted as a key future direction for Navy and is presented in more detail later in the paper. Figure 2 shows the interfaces between NICADMM, the shaded areas, and other ship life cycle functions.

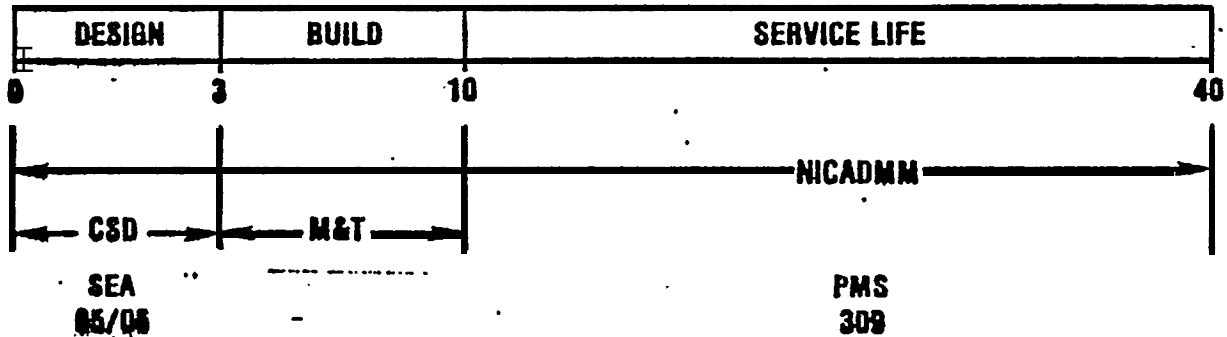


FIGURE 1. Time Relationship of CSD, MAN/TECH and NICADMM Programs

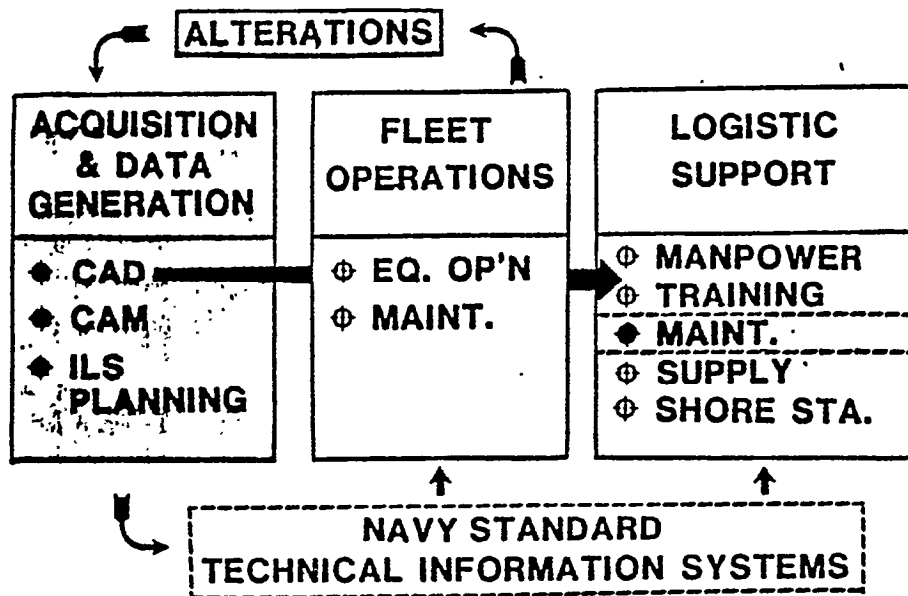


FIGURE 2. NICADMM Interfaces to Ship Life Cycle Functions

Recent Navy CAD/CAM Activities

Mr. Raber's presentation to you three years ago on this subject provided an good overview of the status of CSD [7]. Using that as the initial basis for this discussion, recent CAD/CAM efforts at NAVSEA have concentrated in four areas: development of an integrated ship engineering system; fostering digital data transfer for ship

Projects: and liaison with the marine industry.

Integrated CSD System. The CSD integrated system for ship design engineering is constructed of components common to virtually all such systems, namely: a central data base; a data base management system (DBMS); a system controller program, called SYSEX (System Executive); and ship design applications programs. Figure 3 provides an overview of the relationship of the CSD system components. Supporting these efforts are the implementation of software development standards and initialization of a software toolbox for improving software development efficiency.

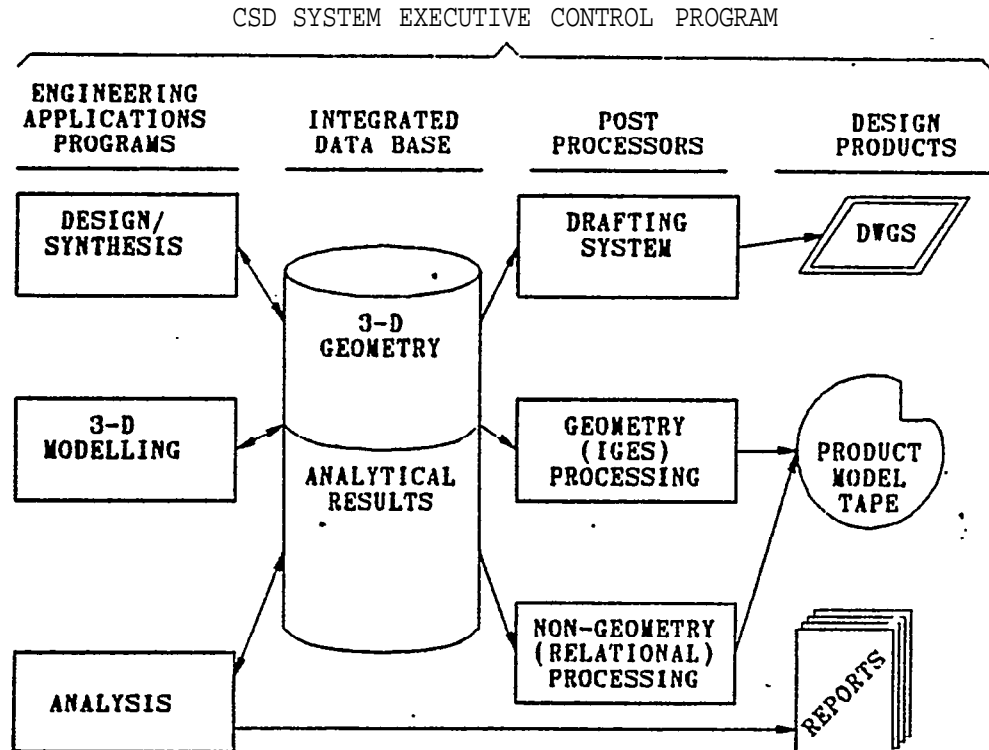


FIGURE 3. Integrated CSD System Components

Integrated Data Base The central data base for CSD is called the IDB (Integrated Data Base) and has been under intense development factor two years now. The central data base is the heart of the CSD system. It will contain both geometric information and analytical results about the ship, including all the data needed to produce the "product model" for later transfer to the shipbuilder. The IDB would additionally contain all data that needs to be exchanged between different engineering organizations and data for ship design project management. Among these, the definition of ship geometry has been the most time consuming and intractable portion of the IDE development. The current concept is to store surface definition information for the ship's hull and internal bulkheads, structural stiffener trace information, and simple bounding prism information for

equipment. Distributive systems, such as Piping and cabling, are not defined in the IDB. This limited sophistication of geometry definition is in line with the level of ship design engineering performed for most surface ship⁵ at NAVSEA but doe⁵ not provide a full S-D geometric representation for subsequent data transfer. It is not adequate for submarine or small ship work and provides limitations to growth as designs become more complex and detailed. As a result, we are now exploring other approaches to designing a data base adequate for a complete geometric definition of the ship.

Data Base Management Systems. Two years ago, the CSD project did a review of commercially available DBMSs in the interest of selecting one for the initial work on the IDB. It was clear that relational DBMSs had "arrived" and were the most desirable choice for our work since they required the least specialized support and provided the most flexibility for future changes as the data base design evolved. Table 2 itemizes many of the evaluation factors used in examining the various candidates.

TABLE 2
DBMS EVALUATION FACTORS

- Ease of use
- Application program interface (primarily FORTRAN)
- Data type⁵ for engineering
- Data structure
- Efficiency
- Flexibility.
- Integrity
- Security
- Recoverability
- Graphics capability
- Report Generators
- Data dictionary
- Application generators
- Screen capabilities
- Utilities
- Portability
- Performance
- Monitoring
- Distributed data
- Vendor support
- Ease of implementation
- cost

The most important factors were: cost; suitability to engineering usage; machine resource impacts; ability to implement it quickly; and availability to run on many different computers to foster data transfer. Least important were performance (speed of execution) and data security since: 1) unlike a DBMS for business purposes, engineering data is not handled as a series of "transactions" but rather in "batches" that closely parallel computer files in size and structure and 2) organizational boundaries are well defined and data access and control are relatively easy to define. On this basis,

Being's RIM (Relational Information Manager) was chosen. RIM is the outgrowth of the NASA and Navy sponsored IPAD project that has become a commercial product [8].

RIM served well as the first DBMS for the IDB and also as an educational vehicle. Its strong points, yet to be duplicated by any other DBMS we have encountered, include specialized engineering data types (matrices and floating point numbers) and low machine resource requirements (although it requires large scratch files for sorting). Its weak points have become ever more important as the complexity of the IDB has grown, including: poor backup and recovery; single user multi user write capability; unfriendly FORTRAN program interface and limited accessory features such as screen formatting and data dictionary. The CSD project has also concluded that other forms of data transfer besides RIM to RIM on different machines are possible and more in line with the general trend toward development of interface standards. In this light, while RIM will still be supported for the single user, a more well developed relational system will likely be utilized, for CSD functions in the future.

system Executive (SYSEX)- Control Program. The current ship design environment requires the examination of a large number of alternative design features, many of them in simultaneous parallel efforts. For example, a single design project may have several candidate hull forms, several general arrangement alternatives multiple main and auxiliary machinery options, and a variety of combat system configurations under investigation at one time. Each combination of these constitutes a variant of the baseline that has some unique data associated with it. With computer based data transfer, some means of identifying the specific ship variant is necessary. There is the additional need to tag the data with a "approval" status, giving the recipient of the information the knowledge of its official standing in the design project. A tracking function is clearly required for each variant of the data base and currently, not conveniently provided by any commercial DBMS. The CSD project thus initiated the development of the SYSEX control program to perform these parts of the data base administration function.

In using the CSD integrated system, the SYSEX program is the gateway to all functions. The **series** of pictures in figure 4 outline the general flow of data and program execution while performing specific engineering design function using the IDB. First, the engineer requests SYSEX to extract data from the IDS and place it in a local file. The engineer then runs his application program using the

extracted IDB data and other data, such as catalogs of information under the control of SYSEX which records the specific version of each data file that was used during the run. Any portion of the program output which is to be returned and added to the IDS is also recorded by SYSEX. Each variant of the IDS for that ship project can have only one approval level: "private"; "proposed"; "released"; "approved" or "archived". This approach establishes a pedigree for each piece of data in the IDE and helps to insure consistency of the total ship data base.

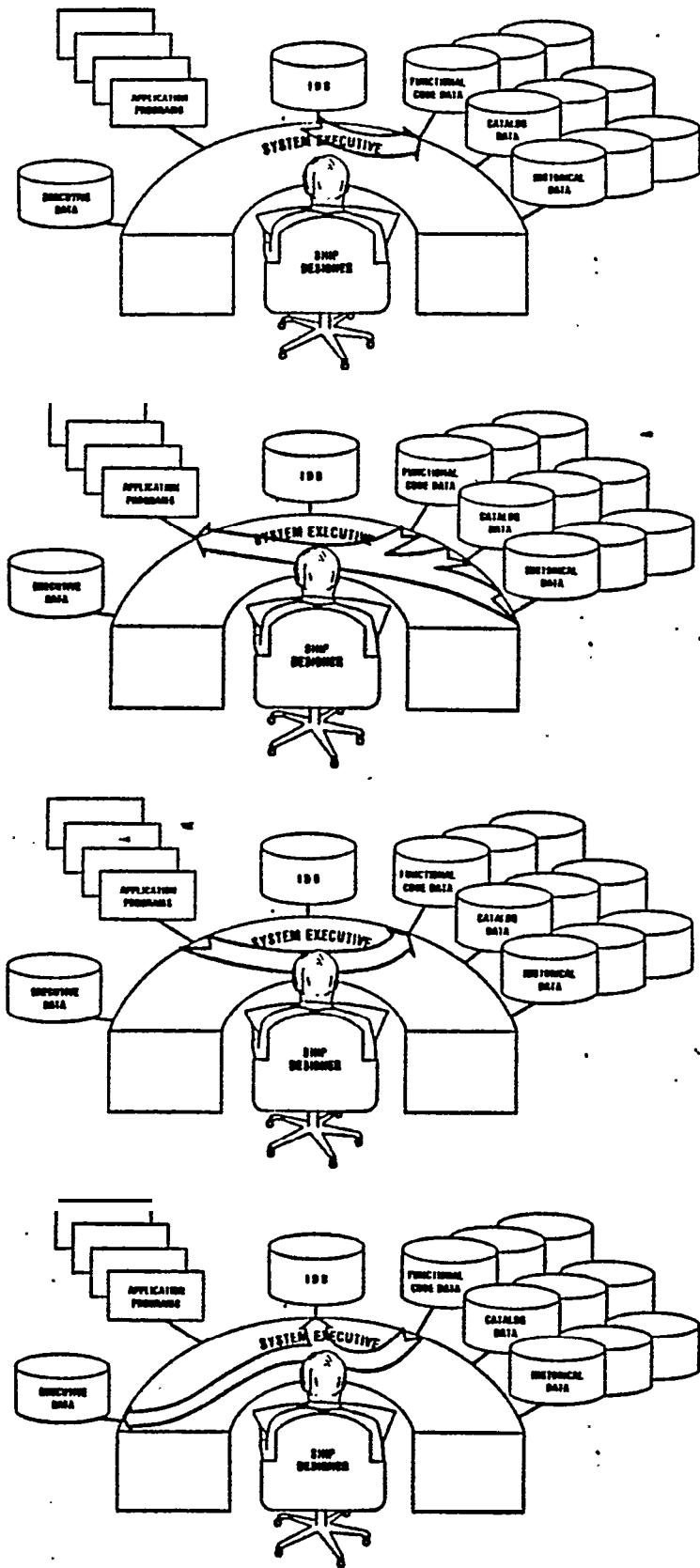


FIGURE 4. Operation of Integrated CSD Design System Under SYSEX

The SYSEX program is useful for keeping track of an individual's files as well as those for the whole CSD system and its use is encouraged for each engineering group. The second version of SYSEX will be operational this fall.

Ship Design Applications Programs. By far the largest part of the development of the CSD system to date has been centered on ship design applications programs. These are mostly unique to the marine industry and not readily available in the commercial market, although that picture is changing rapidly. Since the last report of reference [7], noteworthy project events have occurred in three categories: acquisition of commercial programs; new or improved in-house developed programs; and Computervision utilization. These are briefly described as follows:

- o MOSES (Model Of a Shipboard Energy System) [9] This program was developed in large part by David Taylor Ship Research and Development Center (DTNSRDC) to analyze the performance of shipboard energy systems for applications other than nuclear or oil-fired steam propulsion plants. The program is a simulation model that performs a complete thermodynamic analysis of a user-specified energy system. It offers considerable flexibility in analyzing a variety of propulsion, electrical, and auxiliary plant configurations through a component building block structure. Component subroutines that model the performance of shipboard equipment such as engines, boilers, generators and compressors are available from the program library. Component subroutines are selected and linked in the program to model the desired machinery plant functional configurations. The operation of the defined shipboard energy system may then be simulated over a user-specified scenario of temperature, time and load profiles. The program output furnishes information on component operating characteristics and fuel demands, which allows evaluation of the total system performance. This program is most useful during the very earliest stages of ship feasibility studies when a very large number of alternative machinery plants need to be quickly assessed. It provides key fuel consumption values for input to the ship synthesis models, such as DD08 and ASSET [10,11].

- o CLAM (Compartment Location and Arrangability Model) . This NAVSEA sponsored program is completing its first operational capability this fall and permits the rapid evaluation of combat system space arrangement feasibility. In the earliest design stages, the program uses combat system compartment boundary information and a preliminary list of electronic equipment to enable rapid, simulated 3-D evaluation of the equipment arrangement of the space. Specific criteria, such as allowable cable lengths and maintenance access clearance requirements, can be checked in real time. The main purpose of the program is to determine the feasibility of putting the combat system equipment in the proposed space allocations and estimating an overall figure of merit for alternative space configurations.

- o GADS (General Arrangement Design System). Also coming on line this fall are major geometry modeling portions of the General Arrangements Design System for performing ship arrangement development

throughout Preliminary and Contract Design. This set of programs uses a user friendly inter-face and marine-oriented terminology to aid the engineer in interactively laying out the interior bulkheads and compartment boundaries for an entire ship. It builds on the hull form geometry data that can be generated several different way5 by other programs and transmitted via the IDB. GADS can keep track of area allocation by compartment and produce area/volume reports directly from it5 specialized data base. The GADS system is to be the source of a large portion of the geometry data for the IDB, as previously described, and has been a major undertaking by CSD and the engineering group involved for many years.

- o Enhanced TIGER. The Navy-developed TIGER reliability, maintainability, and availability (R/M/A/) program has become a widely used standard of government agencies, the marine and other industries. Over 200 copies of TIGER have been delivered to this spectrum of user5 in the last 15 years. This fall will see the introduction of a significantly upgraded version of the program, version 8, which has now become the center of a series of R/M/A programs with increased capabilities. Some of the new features include: runs 10 times faster; ANSI 77 FORTRAN throughout; flexible array sizes; added spares/repair options; input error checking; post processing graphics; improved documentation; and compatability with older versions of the input data format. Current users of the TIGER program will receive direct notice of availability of the enhanced version.

- o ASSET Synthesis Model Standardization. The ASSET (Advanced Shio System Evaluation Tool) was originally conceived at DTNSRDC for their use in evaluating the application of new technology to shin design [11]. During its evolution, many program features were incorporated that made for flexibility in modifying the program for new technologies, such as: modular program construction; flexible command-driven input; well-defined internal data structure and management system. These features also proved very attractive from another% viewpoint, that of serving as a common framework for developing ship synthesis models used during Feasibility Studies at NAVSEA. After two years of infusion, the ASSET version 2.0 program has blended the engineering approach of NAVSEA's DD08 destroyer-synthesis program with the Original ASSET program to produce a working prototype for future synthesis model development. This version of the program is currently undergoing acceptance testing at NAVSEA. A whale series Of similarly structured synthesis models for the most popular ship type5 is envisioned.

- o patran is a commercial product that serves as a pre and post processor for popular finite element analysis programs such as NASTRAN and GT STRUDL. It greatly reduces manual preparation of geometry-related information and provides color displays of stress levels.

- o PSS/E (Power System Simulator/Evaluator) is a commercial program that permits complete modeling and analysis of electric power systems. Commonly used in the electric power industry for simulating the characteristics of entire electric grids, it can be used far smaller systems such as ships.

o The TEMPLATE set of subroutines provides a standard mean of displaying graphic data to a wide variety of terminal types including those used at NAVSEA. We will be writing all new Graphics programs using this commercial package as a way of standardizing our software development in this area.

o The Computervision (CV) system has been installed at NAVSEA headquarters for almost two years, currently having eight color workstations and two central processing units. They were acquired primarily to evaluate commercial 3-D geometry modeling capabilities and have proven themselves as extremely powerful tools in this area. They have been applied to several recent ship design projects: the DDG-51 destroyer; SSN-21 submarine; and FFX frigate. Originally used on an experimental basis in parallel with the normal design method, these specialized "turnkey" CAD/CAM systems will become mainstream activities on selected projects. The CV equipment is being used as a prototype for evaluating a radically different approach to geometry modeling than the development of specialized programs that CSD has been sponsoring in the past. This is unfamiliar ground for both NAVSEA and Computervision (and similar "turnkey" systems) because these systems have not been closely tied to engineering application programs in the past, but rather are production-oriented tools. During the ship design process, an estimated 75% of the engineering effort is devoted to analysis, 25% to geometry modeling. It is therefore essential that any modeling system be able to support an intimate interface with analysis programs that require significant general purpose computing capability. The CSD project is currently investigating this issue.

Software Development Standard. Many government standards already exist for software development but almost all are concerned with tactical software, that is computer programs embedded in weapons systems. There is little guidance for the development of engineering software, other than that it use FORTRAN as the standard language. Enter the CSD Software Development Standard (SDS) [12]. This 35 page document contains the bare essentials for guiding the planning, programming, testing and documentation of NAVSEA engineering programs. Carefully distilled from thousands of pages of MIL-specs and other references, the SDS has been invoked in all software development tasks for the CSD project since November 1984. Appendices to the SDS include the two key references that are otherwise hard to locate. The objective of issuing the SDS is to promote the development of quality software that performs to expectations, is well documented and easier to support. While initially somewhat more costly to use than the older "seat of the pants" program development approach, there is no doubt about the long term payoffs in reduced software maintenance costs and longer program life. Copies of the SDS are available directly from the authors.

Software Toolbox A key software productivity enhancing activity initiated this year is the development of a so called "software toolbox", a collection of commercial and in-house subroutines packages that speed and standardize the development of engineering

software. The TEMPLATE package mentioned previously is an example of a part of the toolbox that would fulfill the graphics requirements. Similar sets of subroutines are to be compiled for mathematical functions, plotting aids, document preparation aids, and program debugging and testing aids, to name a few of the categories in the CSD toolbox. The marine industry has recognized the value of a careful approach to software tool development and proposed some recommendations in reference [13]. Quality construction, documentation and support for the toolbox will be a major activity of the CSD project in coming years.

Digital Data Transfer.

The transfer of ship engineering information in computer sensible form between the Navy, engineering agents, and the shipbuilder⁵ has been a subject of increasing interest in the past two years. Among the potential benefits to be gained are: reduced errors and inconsistencies in the Contract Design package; shortened Detail Design time and cost; fewer downstream claims; easier transition to zone-oriented production techniques; return of engineering data for each ship in the "as built" condition to the Navy for improved service life support; linkage of engineering data to shipbuilding and logistics management computer systems in the shipyards and the Navy. Computer technology and interface standards have only recently given us the tools to attempt this with a high probability of success.

The types of products that are currently transferred between engineering activities take the form of two types of paper: text and drawings. Use of the ASCII (American Standard Code for Information Interchange) standard for character data has permitted the transfer of simple kinds of textual data for many years. Sophisticated page formatting or embedded figures cannot be transferred yet and there is little compatibility among the word processors in use but there are signs that a more encompassing standard is emerging in this area in the form of DIF, Defense Information Format. Never-the-less, digital text transfer provides the least benefits from an overall ship design viewpoint because the data is not readily usable for engineering purposes even when available on the computer.

Of more direct use for engineering is the digital transfer of drawings. The IGES (Initial Graphics Exchange Standard) has been developed by the National Bureau of Standards in close cooperation with the CAD/CAM industry specifically to faster digital data transfer between dissimilar CAD computer equipment [14,15]. As shown in figure 5, an IGES transfer involves pre-processing an existing drawing in the native form on one CAD system to produce a digital version of that drawing in a standard format on a magnetic tape. The tape is then physically transferred to another vendors CAD equipment and post-processed to reconstruct the same drawing image in the native form of the receiving CAD system. In principle, all the accuracy and information is retained during the transfer, which avoids the problems encountered if it were loaded in manually from a paper drawing.

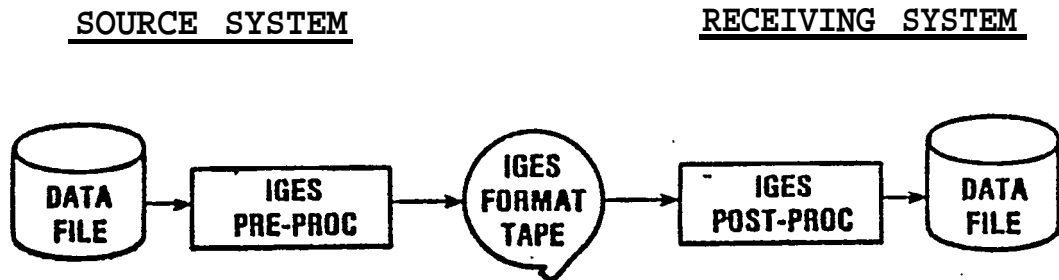


FIGURE 5. IGES Data Transfer Process

A recent test of the IGES capability was performed between several different brands of CAD equipment during the DDG 51 Contract Design effort and revealed many strengths and weaknesses of the early pre/post processors [16]. Despite this, the IGES standard is the only method that exists for performing these transfers and is actively supported by the Navy [17]. With time, the IGES capabilities can be expected to mature and ultimately fulfill the intended function to a high degree.

Liaison With The Marine Industry, The interactions between the Navy and the marine industry relative to, CAD/CAM have grown substantially in the last three years as the overall interest level in computer aided engineering and manufacturing has increased. Since the demise of IREAPS, alternative communication channels have been cultivated, including:

- o Active Navy participation in the SNAME groups concerned with CAD/CAM (Ship Design Panel #2 and Ship Production Panel #4) through regular presentations at panel meetings.

- o DCGA (Defense Computer Graphics Association) symposium panel discussion, December 1984, chaired by one of the authors with Navy and marine industry representatives. Of special interest was the advanced application of computer and CAD/CAM techniques to the DDG-51 Destroyer project [18].

- o Ship design project support involvement by specific shipbuilders on the DDG-51 and SSN-21 projects, particularly in the area of CAD/CAM and data transfer.

- o Monthly newsletter distribution of CAD-related news by the CSD project office at NAVSEA to over 300 government and industry observers [13].

o Navy computer program dissemination by the CSD project office to qualified U.S. industries. Over 250 copies of computer programs were distributed in the past 10 months alone. The Abstracts of Computer Programs [20], widely distributed to Navy and industry in November 1984, summarizes the active library of NAVSEA's ship design application5 programs. Copies are available from the authors.

The Navy in general and the authors in particular have a keen interest in maintaining close contact with the marine industry. We have met with dozens; of representatives and are attempting to foster an open and productive interchange with the shipbuilding community for our mutual benefit.

FUTURE CPD/CAM DIRECTIONS FOR NAVY

The ability represent all forms of information digitally through the use of computers is revolutionizing the way we do business. Wireframes, Surfaces, and now solids provide a means to manipulate geometry in three dimensions previously not possible. Interaction by designers with computers through graphics provides a vehicle by which designs can be driven from a producibility and maintenance perspective, resulting in end products of superior quality. From a Navy standpoint, this means weapon system5 of increased capability at reduced costs which can be maintained and modernized much more readily than in the past. Thus, a ship weapon system can be maintained in a high state of readiness and be a viable system throughout it5 operational cycle. Coupled with data transfer standards, computers could free the engineering community of many of the problems of using paper as a means of exchanging data.

During the past three years, the Navy has become increasingly interested in the potential of CAD/CAM as a key element in the life cycle management of weapon systems. More recently, the U.S. Senate Appropriations Committee report on the Department of Defense Appropriations Bill, 1985, contained this except:

"The Navy **is** instructed to report to the Committee on the potential expansion of computer aided design and manufacturing techniques at naval shipyards and engineering centers. "

The report also noted 30 percent reduction of targeted costs in private shipyards and that the Navy has invested 5 billion dollars in business related ADP systems but less than 100 million in CAD/CAM. The Committee is correct. Application of CAD/CAM technology **is** expected to produce substantial reduction of Navy material acquisition and logistic support costs.

The Navy is in the initial stage of an effort to realize the benefits of CAD/CAM technology. The potential program is being addressed now in POM-87 programming. In responding to the Chairman of the Senate Committee on Appropriations, Secretary of the Navy John Lehman stated in his letter:

"We are convinced, based on industry's experience, that CAD/CAM will result in significant savings to the Navy. We are reviewing candidates from a pilot program and expect to select one as a significant project by the fall of 1985. "[2]

In arriving at this conclusion, the Navy, under the direction of the Program Manager, NAVSEA Information Systems Improvement Program developed a three part report, including: overall Navy CAD/CAM experience, findings and organization; Naval SEA Systems Command (NAVSEA) CAD/CAM actions and plans; and other Navy CAD/CAM planning.

Overall CAD/CAM Experience, Findings and Organization

Past Navy CAD/CAM Experience. The Navy has monitored the technology and conducted small CAD/CAM efforts since 1364. The three principal past CAD/CAM efforts - all still ongoing - are the CSD ship design CAD program in NAVSEA headquarters, a small CAD/CAM program in Navy Laboratories, and the recent procurement of CAD/CAM equipment for Navy Laboratories and three system commands under the CREDSOS program. As noted in the Senate report, investment in these Projects has totalled approximately 100 million dollars. Past Navy experience and private sector experience indicate that CAD/CAM technology can benefit the Navy importantly.

Findings. U.S. auto makers, during 1980-4, invested in CAD/CAM amount reported in the press as 60 to 80 billion dollars. During the first quarter of 1384, U.S. auto makers produced automobiles at a rate two percent greater than the 1978 rate with 23 percent fewer workers and quality was substantially improved.

Table 3 lists other private sector data from 1983-4 industrial publications and a National Research Council (NRC) study. These data confirm that CAD/CAM can produce substantial cost, time, and product quality improvements. Reducing change orders and rework of failed parts and subsystems is an important source of cost reduction. The quality implications are important to Navy operational availability and reliability.

Table 3

OTHER PRIVATE SECTOR RESULTS

OTHER PRIVATE LAWYERS					Factory Test
<u>Company</u> /Product	Labor	C_o	s_t	L_a_b	<u>o_r</u>
		(percent reduction)			
From literature					
Rockwell International		-30		-70	
Messerschmidt (FRG)			-44	-25	
Nigaata/engines(Japan)			-67	-75	
Grumman	-66				
General Electric					-75

From NRC report			
Computers	-50	-84	-80
Dishwashers	-40		-70
Cutter5	-50	-76	-76
Electronics	-38		

Navy CAD/CAM will be applied principally in the Naval Material establishment. NAVSEA CAD/CAM applications are expected to be half of the total Navy CAD/CAM applications, as measured by investment and return.

Organization of Navy CAD/CAM.. The Chief of Naval Material on 28 July 1383 assigned NAVSEA to formulate and manage, as lead systems command, a NAVMAT CAD/CAM program. The Commander, Naval Sea Systems Command in turn assigned the program responsibility to the Program Manager, Information Systems Improvement Program, PMS 303, who report directly to the Commander of NAVSEA. The title of the resulting, budding program in NICADMM (Navy Integrated Computer-Aided Design, Manufacturing, and Maintenance program), pronounced Nick Adam. A Navy CAD/CAM Liaison Group was established in 1983 and has been operating for one year. The group is chaired by the NICADMM Program Manager. Membership includes representatives of all five Navy system commands; the Director of Navy Laboratories; and the Director, Strategic Systems Programs. The functions of the Group are to assist the Program Manager in managing the NICADMM Program, review standards and exchange related information.

NAVSEA Actions and Plans

The NICADMM Program will provide centralized management of Navy CAD/CAM; promulgation and enforcement of technical standards applicable to all Navy CAD/CAM; and centralized (fully competitive) procurement of standardized equipment and system software. Development of application systems will be decentralized. NICADMM currently includes NAVSEA applications, and planning is underway for expansions to other system commands. Whether to budget for other CAD/CAM applications as part of NICADMM or separately has not been decided. Development of other applications will follow one to two year5 behind corresponding NAVSEA applications development, to avoid duplication of pathbreaking costs and for other reasons cited later.

~~Relation to Other Functions and~~ Technical Data Systems. Naval ship technical data re used typically for 35 to 45 years after the data are created. As indicated in Figure 6, design data for each naval ship class are created during! development of ship element systems and design of the lead ship of the class. Production planning is completed in parallel with the final design stage and is applied during ship construction. Instructions for shipboard operation and maintenance of equipment and shore-based and sea-based integrated logistic support (ILS) are produced during construction of the lead ship and applied during the service lives of the ships. Design and other data are changed during the service lives of ships as combat and other element systems are updated by alterations to the ships.

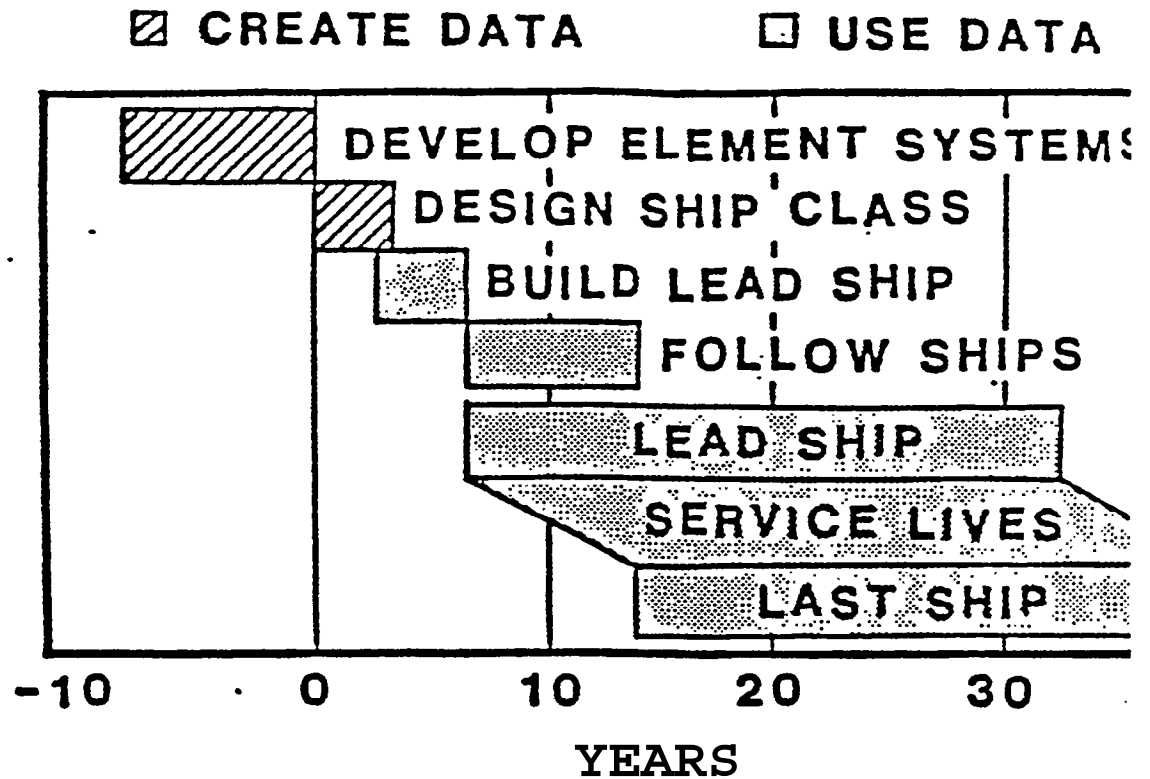


FIGURE 6. Life Cycle of Ship Class

Figure 2 indicates that NAVSEA CAD/CAM application systems will be applied in ship acquisition, ship alteration, and shore-based ship maintenance. The figure also clarifies the relations among these application systems, Navy standard technical information systems, ship acquisition, ship alteration, fleet operations, and logistic support.

investment and Net Effect Projection. The NICADMM Program plan is based upon the following assumptions. First, CAD/CAM operating cost will replace substantially larger costs associated with current methods. Second, investment rate will determine the rate of realizing net cost improvement. Figure 7 applies to program performance and illustrates conclusions drawn by applying private sector experiences conservatively in a net effect computer model. The more assumptions are that, for each investment increment, more of the cost improvement will be realized in the first program performance year after the increment is applied, 30 percent of the three-year return will be realized during the second program performance year, and 7.0 percent of the three-year return will be realized during the third program performance year and each successive year. Succeeding paragraphs explain the figure.

The curves in this figure represent net cumulative financial effect, that is, cumulative cost savings minus cumulative investment. The curve assigned a probability of 0.1 corresponds to a 7:1 three-year payoff, which is optimistic. The curve assigned a probability of 0.5 corresponds to a 4:1 three-year payoff, which is typical of CAD/CAM investments. The curve assigned a probability of 0.7

corresponds to a 2:1 three-year payoff, which is considered mediocre in the CAD/CAM community. For a wide range of probabilities, performance will lie between the two outer curves.

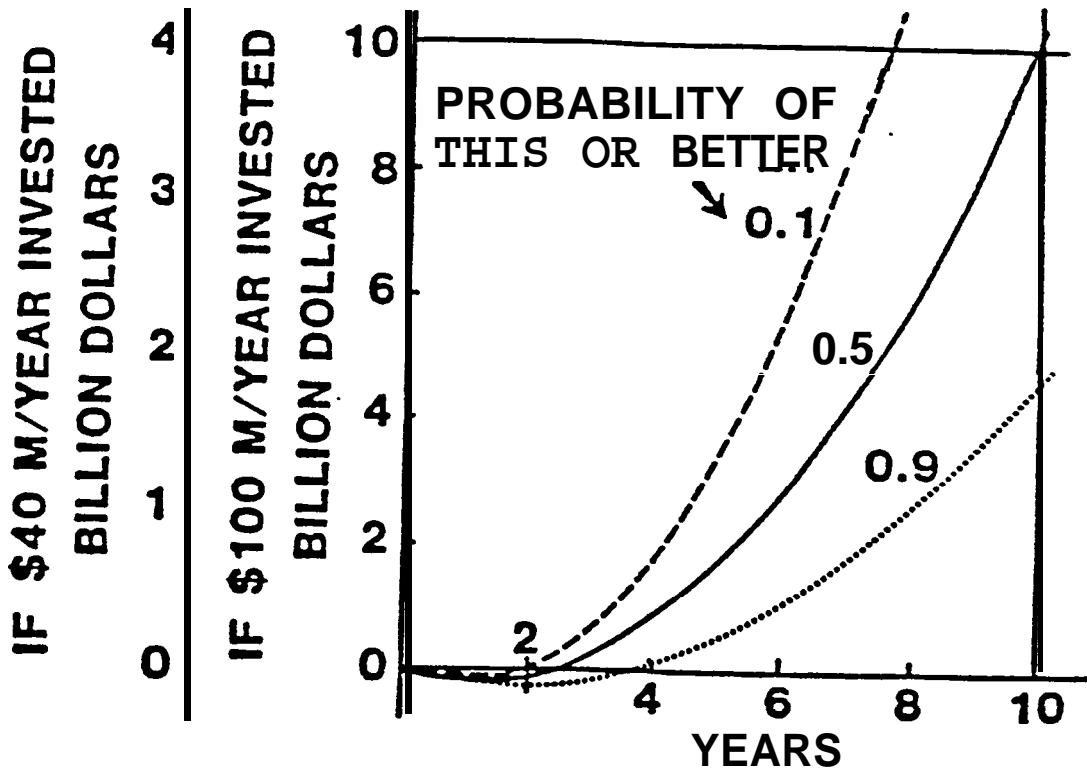


FIGURE 7. Net Financial Effect of CAD/CAM Investment

The break even Points, where the curves cross zero net effect, occur two to four years after the starting point. The net effect curves start down because the investment rates initially exceed the return rates. They bottom out where the return rates begin to exceed the investment rates.

The vertical scale depends upon the investment rate. For the most likely case (0.5 Probability curve) and if the investment rate is 100 million dollars per year, the projected ten-year net effect is plus 10 billion dollars (11 billion returned minus 1 billion invested). For the most likely case and, if the investment rate is 40 million dollars per year, the projected ten-year net effect is plus 4 billion dollars (4.4 returned, 0.4 invested). These two investment rates are high and low limits of recommended NICADMM program funding during the early years. An optimal rate in later years may be higher than 100 million dollars per year.

NAVSEA study, the NRC report, and other expert opinion sought by the Navy indicate that the foregoing projections should be wholly applicable to Navy material design, manufacturing, and maintenance. Testing of this key conclusion is being approached prudently.

NICADMM Program Status

A number of NICADMM Program management steps have been complete since the Chief of Naval Material assigned CAD/CAM program management to NAVSEA in mid-1383:

1. Liaison with the Air Force ICAM and Army ECAM programs has been established.
2. The CAD/CAM Liaison Group has established the state of all Navy CAD/CAM actions and adopted an overall Navy plan.
3. The NICADMM Program is included in the Department of the Navy Information System Plan dated June 1384.
4. A National Research Council advisory study (partially funded by NASEA but created with NRC's usual independence) has been published and calls for an immediate Navy-shipbuilder program.
5. A Mission Element Need Statement (first major top management decision paper for a new DoD program) has been prepared and is being reviewed within the Navy.
6. A program management plan (less appendices) has been prepared and reviewed by all potential participants. The acquisition plan and 17 other appendices to the program management plan are being prepared.

A brief summary of the technical status of Navy CAD/CAM follows.

1. The CAD/CAM Liaison Group has reviewed initiatives by individual activity commanders and program managers. The initiatives were well justified and generally successful.
2. The status of on going CAD/CAM equipment installations under the CAEDOS program in systems commands' activities as of September 1981 was:

SYSKOM	Activities	Planned	Installed	Percent
NAVSEA	13	\$17.8 M	611.8 M	66
NAVAIR	13	7.0	6.2	83
NAVFAC	14	8.9	8.5	36

This equipment was procured from the Navy Laboratories' CAEDOS contract administered by Naval Weapons Center, China Lake, California.

3. Results to date, in the affected NAVSER areas, show design costs down 48, percent, two-dimensional layout costs down 28 percent, drafting costs down 42 percent, and cost of preparing bills of material down 20 to 50 percent.
4. More importantly, engineers in 40 Navy activities are being trained to apply CAD/CAM. The training effort is more than paying for itself, but that fact is less important than laying the foundation for larger gains.

5. A second, larger CAD/CAM equipment procurement for all systems command5 is being planned by the NICADMM program office.

Data- Exchanges. The IGES specification previously noted has become a de_ facto national standard. IGES is open ended in the additional conventions can be added, Just as spoken languages grow. NAVSEA invoked IGES in August 1984 for all naval shipbuilding and is planning shipbuilding additions to the IGES conventions. Shipbuilders welcomed the IGES requirement and concur in the need for additional shipbuilding conventions. The Navy invoked IGES as the standard for all intra-Navy and Navy-contractor CAD/CAM data exchanges in the Naval Material establishment in February of 1985

NICADMM Program Technical Plan. The NICADMM technical plan has part5 affecting only NAVSEA activities (principally naval shipyards; naval ordnance plants; supervisors of shipbuilding, conversion, and repair; and engineering centers). It also has parts affecting both NAVSEA activities and private shipyards and other parts affecting all Navy CAD/CAM. Based upon lessons from the private sector and advice from consultants with extensive CAD/CAM implementation experience, the NICADMM technical plan requires initiation of two preparatory steps before undertaking major program performance. Funding decisions being made currently may affect the schedule. The schedule will become firm after the corresponding funding decisions are made.

Standards and Selectina Planningl Criteria and DevelopmentThe technical plan for the first preparatory step has; two parts. The first, part is to select and adapt from successful CAD/CAM programs the following `standards for all Navy CAD/CAM.

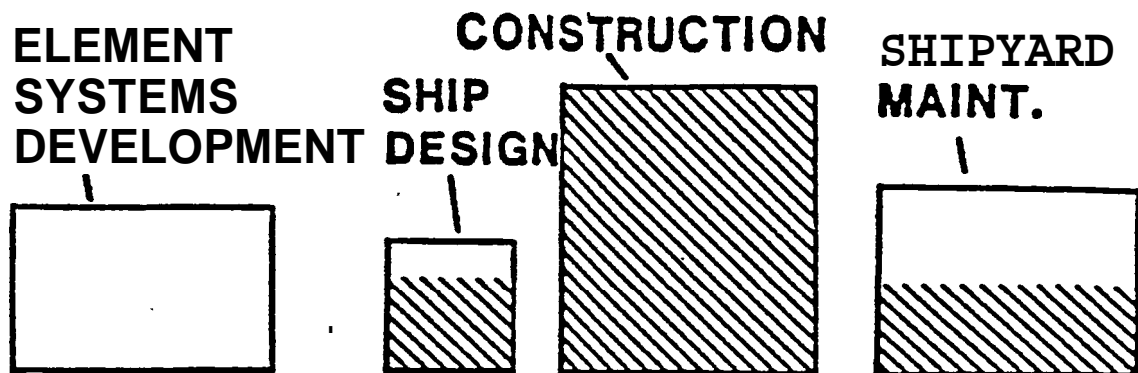
System Software and and Equipment	Application Methods
Data management system	Application analysis
Operating systems	Application design
Languages	Programing
Graphic software	System testing
Software tools	Documentation
Mainframes	Implementation
CAD equipment	Rcceptance
Professional computers	Evaluation
Drafting equipment	Maintenance
IGES (done)	Alteration

The second part of the first preparatory step is to establish -criteria for selecting NAVSEA application development increments. The primary aim5 are to advance total production capabilities of NAVSEA activities (vice creating islands of automation) and obtain early payoffs. There are an abundance of candidate CAD/CAM applications. The need is to select and schedule for development the combination that most rapidly will reduce the tar-get costs and the time periods ships are in shiyards, and improve product quality. Performance must proceed via incremental expansion of a nucleus system. Selection of the nucleus system is a critical factor.

A substantial amount of planning is involved. The Navy must study for the affected activities--production cost factors, schedule critical paths, and product quality factors; existing relevant CAD/CAM systems; for each candidate development -- the investment amounts, development schedules, and expected benefits; interrelations among candidate developments; and the relations of various combinations of candidate developments to overall cost, time, quality, and investment effects. This planning will be performed in a series of iterations, each reducing the number of candidate developments.

The NICADMM technical plan for the second preparatory step is to perform more detailed planning, evaluation, design, and scheduling of selected candidate NAVSEA applications. The evaluation criteria will be net effect on quality, cost, and time; investment profile; return.. (benefits) profile; and state of preparedness to undertake each increment. The end product of this planning will be detailed plans for the first four to six program performance years and tentative plans for later years.

⊕ POTENTIAL GAIN



⊕ CAD/CAM EXPERIENCE

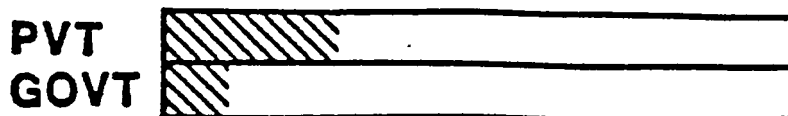


FIGURE 8. Private Shipyards' Role

Private Shipyards' Role and Data Ease Design. The sizes of boxes in the upper part of Figure 8 indicate roughly the relative cost improvements obtainable in each area, except that cost improvement in element systems development has not been estimated. NAVSEA applications effort during the first several years will focus upon ship design, ship construction, and ship maintenance. The shaded parts of the corresponding boxes indicate private shipyard operations. The unshaded parts signify operations of government-owned facilities.

The bottom part of Figure 8 reflects the fact that private shipyards have accrued more CAD/CAM experience than NAVSEA activities. NICADMM Program execution has and will include seeking advice and assistance from organizations with greater CAD/CAM experience including private shipyard;.

As indicated in Figure 6 greater cost improvements in naval ship design, construction, and maintenance can be obtained in private shipyards than in NAVSEA activities. In addition, the major parts of the data base (technical data describing ships, construction plans and ILS plans) are created during the latter stages of ship design and during construction, which are both performed by private shipyards.

The next step after IGES in a Joint Navy-shipbuilder effort must be to (1) select suitable data management software systems (being performed by NAVSEA) (2) define data base content - after the ships are in the fleet, at the end of construction, and at the ends of various design stages - and (3) define methods for creating the required content. The data base design will vary for different production systems, that is, different shipyards building and/or maintaining different ship types, but the first complete design will be mostly (70 to 90 percent) reused in subsequent naval and private shipyard applications. The alternatives are to define a partially standardized, Navy-initiated data base design, at a cost of 6 million dollars, or incur indirectly the greater cost of each private shipyard's separately developing a shipbuilding data base design. Good cost estimating data for data base design and development are available for GM and Boeing.

Because the Navy no longer operates a building shipyard, the data base design effort must be performed mostly by two or more private shipyards, with NAVSEA participation for tasking and coordination and to cope with the fact that the results will involve proprietary information that private shipyards will not be willing to exchange with each other. This effort will include the needed IGES extensions and several other required technical elements (definition of drawing layers, group technology, and other CAD/CAM-peculiar factors).

Other Navy CAD/CAM Planning

Navy Laboratories will continue their ongoing limited CAD/CAM efforts. The major additions will occur in the Navy's system commands. All Navy system commands will develop CAD/CAM programs. As explained earlier, the Navy will apply the standard developed in the NICADMM Program to all Navy CAD/CAM.

Naval Air Systems Command. The Naval Air Systems Command (NAVAIR) program is expected to be the second largest Navy CAD/CAM program. It will be the most complicated to formulate because of the requirement for extensive liaison with the Air Force and the aerospace industry, which already has major CAD/CAM systems. The NICADMM program office is assisting NAVAIR in initiating required planning. As indicated earlier, 13 NAVIR activities are using CAD/CAM systems and training engineers.

Naval Facilities Engineering -d----- The Naval Facilities Engineering Command (NAVFAC) has formulated a CAD/CAM program. It reflects the state of CAD/CAM in the architectural, engineering and construction (AEC) industry.

The AEC industry is moving rapidly in CAD applications but has few CAM applications. The Design/Construct 1983 (seventh annual) survey indicated that, of the 220 largest AEC firms, 33 percent now use CAD systems and an additional 26 percent plan to purchase such systems in the near future. AEC firms using CAD systems have achieved improved design analysis, better design quality, and, faster completion of projects. The accumulation of design data bases also will enhance building renovations and life cycle operating and maintenance. Most of this progress has occurred during the past three years. It is expected that, when the AEC industry has sufficient experience to produce net effect data, the results will be similar to the results for other CAD applications.

The NAVFAC CAD/CAM program budget will be smaller than the NAVSEA NICADMM Program budget for a number of reasons. First, the NAVFAC Program does not encompass major CAM elements, and will not do so until the AEC industry advances to that point. Second, universities and industry have produced many civil engineering software packages that can be applied by NAVFAC. Third, NAVFAC has established effective liaison with the Army Corps of Engineers to avoid duplication of work and share advances.

Naval Space and Warfare Command The Naval Space and Warfare Command CAD/CAM program necessarily will lag behind the NAVSEA program. The electronic systems acquired are installed in ships, aircraft, and shore stations. Ship installations are the largest segment. Prime contractors have extensive CAD/CAM experience and Space and Warfare Command has a strong computer systems capability. The Space and Warfare Command CAD/CAM systems however will feed into the NAVSEA, NAVAIR, and NAVFAC CAD/CAM systems, and the latter are not yet defined. It is anticipated that this command will make rapid progress after the foundation has been prepared in the NAVSEA application.

NAVAL Supply Systems Command. The Naval Supply Systems Command (NAVSUP) is the lead system command for Navy Standard Technical Information Systems, and has corresponding Triservice responsibility. The relation between these systems and CAD/CAM systems was illustrated in Figure 7 and was explained earlier in the presentation of the figure. Current related NAVSUP effort is focused on this aspect of its responsibilities. Navy Standard Technical Information Systems and a related but separate budget item. NAVSUP will address its international CAD/CAM applications at a later time. NAVSUP's most important current contribution to overall Navy CAD/CAM effectiveness is to assure a good fit between NICADMM applications and Navy Standard Technical Information Systems.

CONCLUSION

The National Research Councils report on shipbuilding productivity [21] strongly recommended Joint Navy and industry development of common engineering data bases and CAD/CAM systems to facilitate achievement of this goal. As you can see, the Navy is taking an active role in helping to shape the future of computer applications to the engineering functions for the ship's entire life cycle primarily through the CSD and NICADMM programs already noted. These initiatives are based primarily on the premise that CAD/CAM technology can be utilized to automate all the functions in the product development process as shown in Figure 3. There are many problems, which require solutions. Three aspects of these programs will become increasingly important in this regard: setting standards with industry for the exchange of engineering data; acquiring the software and hardware tools for development and handling of this data; integrating and operating a Navy-wide engineering data base system throughout the life cycle of each ship. The real driver behind these is, of course, the definition of the engineering data base itself.

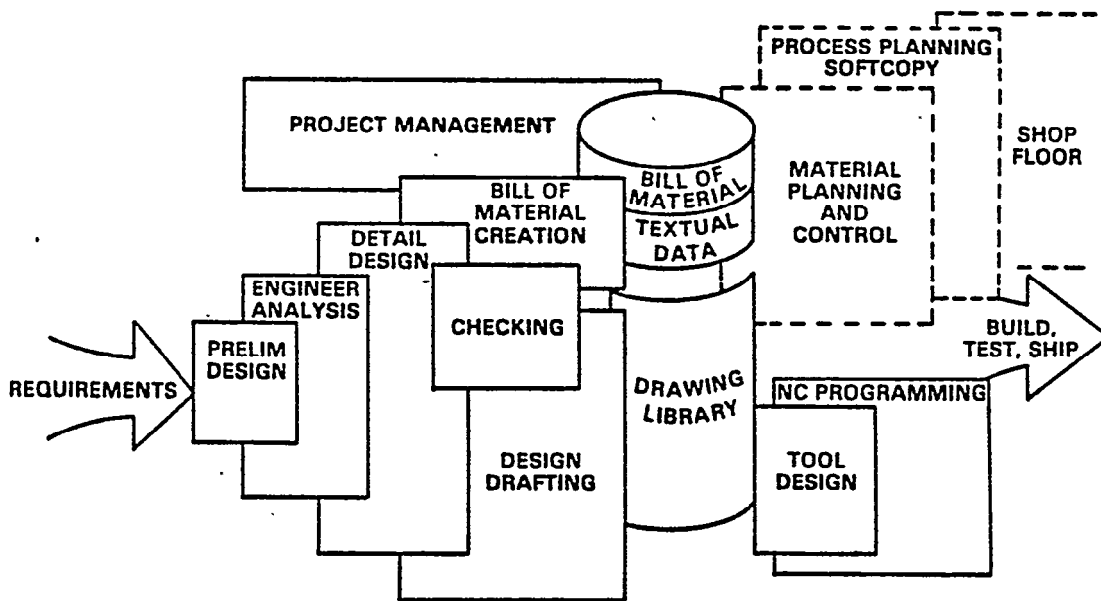


FIGURE 9. Product Development Process

The current state-of-the-art in geometry-oriented data transfer is centered about the digitization of current paper-based engineering products. The IGES specification is the prime example of this approach. However, it is extremely difficult to accurately and consistently define a 3-dimensional object like a ship with a set of 2-dimensional drawings. Drawings are also not directly usable for automated production techniques. Even if completely dimensioned-3 and self consistent from view to view and drawing to drawing, which is a

rare occurrence, drawings do not define what is between the sections that are shown on each sheet. In other words, what is missing are the "rules of interpolation" for determining the value of any point in the third dimension. This lack of definition is particularly acute when complex shapes are involved, such as the ship's hull, many of the structural members and virtually all of the equipments. It was for *this* reason that scaled "half models" of the ship's hull form were used by naval architects during the days of sailing vessels to communicate to the shipbuilder what hull shape was desired. Thus, drawings should be thought of as matters of convenience, merely projection of three dimensional objects into two dimensions, a far cry from the full definition of the physical object. Ultimately, what is desired is not digital versions of 2-dimensional drawings, but instead, a digital representation of the entire ship containing complete S-dimensional geometric design and manufacturing information. This body of data has come to be known as the ship "product model", although a rigorous definition does not exist. It would include full geometric information and attributes of that geometry in sufficient detail to construct the product. It would contain the manufacturing information about the ship as actually constructed in a form that would permit complete replication of parts for repair and overhaul work throughout the ship's life. Computers provide the only practical mechanism for defining and transferring product models.

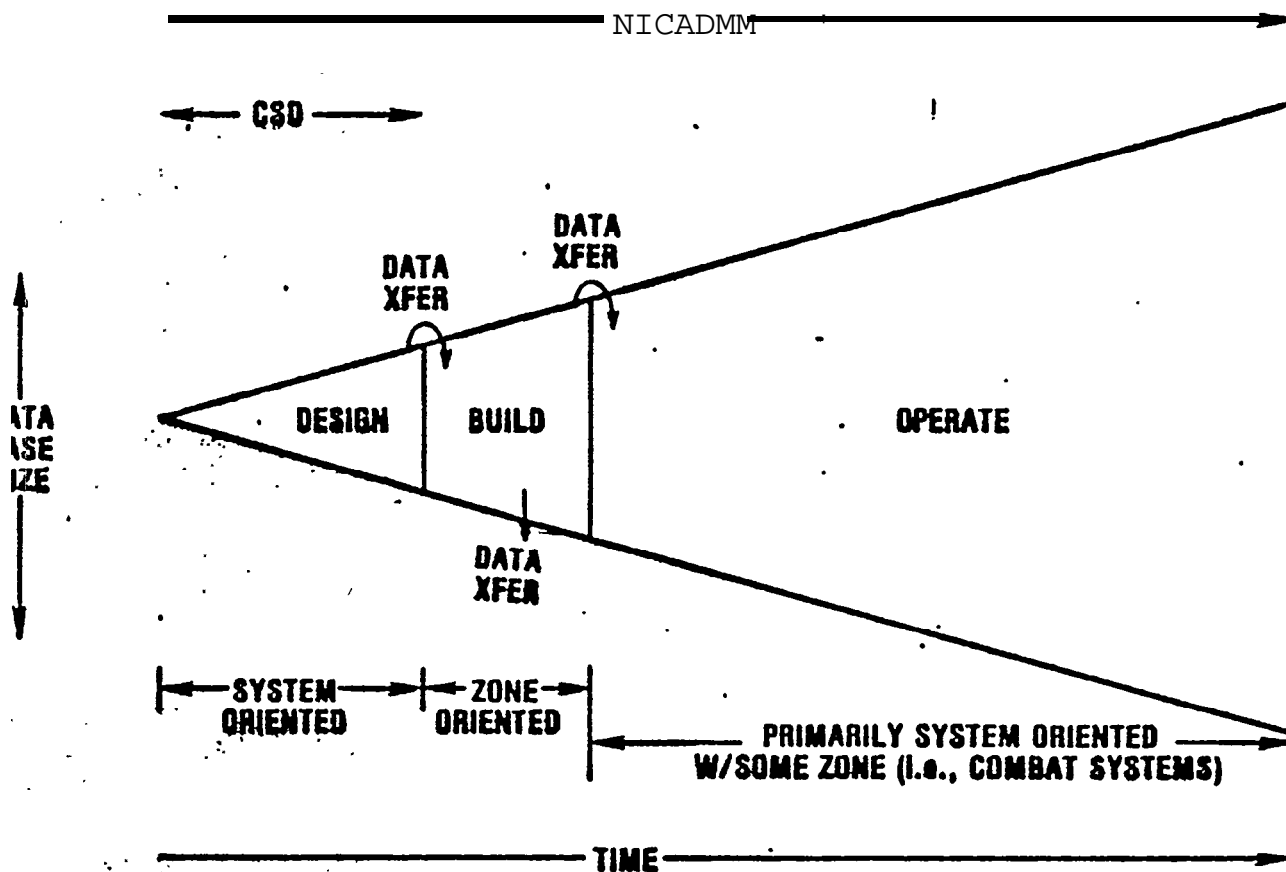


FIGURE 10. Product Model Data Base Life Cycle

The product model is not a stagnant body of data but evolves and grows throughout the life of the ship as depicted in figure 10. At key junctures, the product model would be transferred between the Navy and the shipbuilder, at the end of Contract Design and again at the end of construction, or between lead and follow shipbuilders at the end of Detail Design. These are the main data transfer points at which the definition of the product model needs to be standardized throughout the industry. The engineering methods and data bases used within the "design", "build" or "operate" phases could be left undefined, able to be tailored to the specific needs of each agency or shipyard. This would provide us with a common language for data exchange at these interfaces, while permitting almost unlimited flexibility for individual activities to do what is best for them.

The application of computer aids for engineering design, manufacturing and service life maintenance of Navy ships has been a continuing priority for the Navy and the marine industry for many years. The Navy has developed an organization and plan for major expansion of computer aided design, manufacturing, and maintenance encompassing overall management of Navy CAD/CAM, NAVSEA CAD/CAM applications, the Navy-shipbuilder interface, and NAVFGC CAD applications. This plan will be executed as soon as related funding decisions are made.

Only recently has the power of the computer actually started to approach our vision⁵ for its usefulness. The next few years will be crucial ones for setting the standards and developing the tools to fully harness this power. There are opportunities here that may not come again and must not be passed by. Capitalizing on them will take a dedicated, Joint effort on the part of the entire industry.

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